A Mobility-Aware Adaptive Power Control Algorithm For Wireless LANs, a Short Paper

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Abstract— The rapid emergence of wireless 802.11 LANs in home/office environments and the limited battery life of portable laptops motivate the need for low power communication. Power consumption of the radio interface can be reduced by lowering the transmit power to the minimum level that maintains communication. In this paper, we present a distributed transmit power control algorithm implemented on 802.11 ad hoc LANs that is adaptive to mobility. Exponentially smoothed measures of the average and deviation of the received signal strength are used to distinguish true mobility events from spurious multipath noise.

***Index terms*—mobility, wireless, power control, adaptive**

I. INTRODUCTION

Wireless LAN communication standards such as WiFi 802.11b have been rapidly adopted into offices and homes. Wireless communication gives the end user untethered access to remote data and hence the freedom to roam. The design of mobile communication systems introduces a variety of engineering challenges. In particular, portable wireless devices such as cell phones, wireless PDAs and 802.11-enabled laptops are resource-constrained in terms of limited battery lifetime. As a result, low power communication is essential in order to extend the lifetime of the wireless device.

Low power communication can be achieved via two techniques: decrease the time of communication either by idling the radio [Jin, Kravets, Singh98a] or by compressing the amount of transmitted data; or reduce the transmit power [Monks2000, Monks2001]. Transmit power control is complementary to radio idling and compression so that all techniques can be used in concert to achieve low power communication. This paper focuses on the technique of transmit power control, when the radio is actively transmitting, to limit power consumption and simultaneously be able to be generalized in principle to distributed transmit power control in other wireless networks such as Bluetooth RF and IR-based wireless sensor networks. Ideally, the transmit power can be lowered to the minimum level that still achieves correct reception of a packet despite intervening path loss and fading. Our transmit power control algorithm is unique in its adaptation to mobility, its adaptation to noisy multipath fluctuations in received signal strength (RSS), and its flexibility to asymmetric channels, i.e. separate path losses can be calculated in each direction so that bidirectional symmetry need not be assumed.

Initial work on transmit power control in wireless ad hoc networks is confined to a simulation environment with theorotical analysis For example [Monks2000, Monks2001] proposed approach assumes the existence of two separate channels for data and control, which makes the solution infeasible to implement in current 802.11b ad hoc networks. In addition, the approach is not adaptive to mobility.

Other work [Narayanaswamy] selects a common minimum transmit power for all nodes equal to the minimum power at which the network displays the same connectivity as that displayed at the maximum transmit power. However, this approach requires modification to MAC packet headers and maintaining network connectivity routing tables for each transmit power, which limits incremental deployment as discussed later.

Another power control protocol exploits the difference between the carrier-sense region in which a transmission can be detected from the transmission region in which a packet can be decoded [Jung]. The authors propose transmitting the RTS/CTS at maximum power while also intermittently transmitting data packets at maximum power, in order to prevent collisions. The approach does not address mobility and also makes the assumption that path loss is symmetric between two nodes.

Adjusting transmit power will affect the connectivity of a wireless ad hoc routing network in ways which are not yet well understood by the networking community. Decreasing/increasing the transmit power between nodes causes the network graph, which is used to compute the minimum-path routes, to fluctuate across sparse and dense interconnection modes. In the absence of transmit power control, nodes transmit at a fixed default power, so that a link power cost can be assigned for each link. In addition, each node can monitor its current battery power level. Given node power costs and link power costs, a variety of minimum-energy routing algorithms have been developed based on such metrics as choosing the path with the maximum sum total of battery life, selecting the routing that minimizes the sum total of energy expended, and selecting the path with the strongest "weakest" node, i.e. maximizing the minimum energy [Chang, Gomez, Li2001a]. The latter max-min strategy maximizes the time to network partition, which becomes far more complex when adaptive transmit power is introduced. The effect of transmit power control on ad hoc routing is a policy question of *whether* to employ power control, rather than *how* to apply power control. This paper presents an algorithm that focuses on how to apply power control in the presence of multipath noise and mobility, and leaves the policy question of whether to employ power control to entities, e.g. ad hoc routing algorithms, beyond the scope of this paper.

II. ALGORITHM

The primary objective of our work is to design, implement and test a distributed adaptive transmit power control algorithm for wireless LANs that is able to simultaneously:

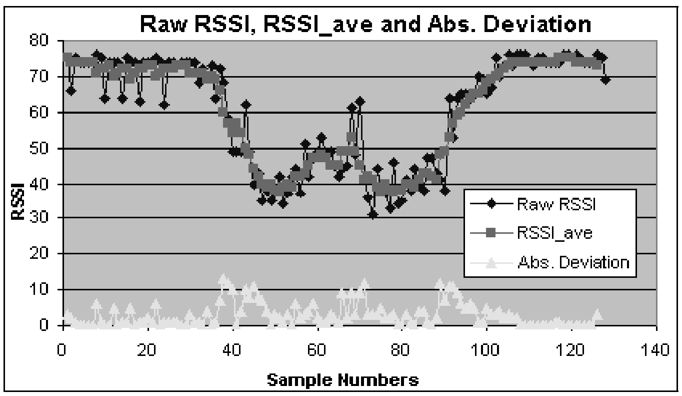

Figure 1. Multipath-induced short-term fluctuations, long-term mobility-induced variations, smoothed average of Received Signal Strength (RSS) and absolute deviation over time.

- Minimize power consumption in node-to-node communication
- Adapt to mobility of one or both endpoints
- Maintain the connection while minimizing packet loss caused by multipath noise

In addition, our solution should also be bandwidth-efficient with limited messaging overhead, incrementally deployable, and generalizable to non-symmetric channels.

In our algorithm, for each packet, the receiver computes the unidirectional path loss, equal to the difference between the transmitted power and the received signal strength (RSS). The optimal transmit power between a sender-receiver pair can be represented as

$$P_{TxOpt} = \text{Path Loss}(t) + RSS_{min} \qquad (1)$$

where a variety of effects including multipath fading, shadowing and path loss are grouped under the term “Path Loss”. RSS_{min} is the minumum threshold below which correct reception of a packet cannot be guranteed by the hardware radio (-80 dbm for Cisco Aironet 350 cards). In practice, the lower limit of the transmit power is 0 dBm for these cards, and P_{TxOpt} becomes the minimum of 1 mW and Equation 1.

Equation 1 is a tight bound and P_{TxOpt} would keep the sender and receiver just barely connected. In practice, the RSS varies with time even at a fixed location due primarily to short-term multipath-induced noise. Figure 1 shows a trace of 802.11 RSS measurements collected while stationary (samples<30 and samples>100) and while there is mobility (30<samples<100). Since RSS variation causes path loss variation, then adhering to the tight bound of Equation 1 will result in unnecessary loss of packets whenever RSS momentarily falls below RSS_{min}. To avoid such unnecessary below-threshold packet loss, we placed a cushion M_{thresh} above the tight bound of Equation 1, boosting P_{TxOpt} so that the RSS stays above RSS_{min} even with path loss fluctuations [Sheth]:

$$P_{TxOpt} = \text{Path Loss}(t) + RSS_{min} + M_{thresh} \qquad (2)$$

In [Sheth], a fixed M_{thresh} cushion of 3 dBm above RSS_{min} for all data was found to be large enough to prevent most below-threshold packet losses in typical cases, and was small enough to still achieve considerable power savings through reduced transmit power. However, such a fixed cushion does not adapt well to RSS behavior with deviation much greater or much smaller than the fixed threshold, and wastes power when the RSS deviation is also changing over time rather than being fixed. M_{thresh}, or the amount of boost to P_{TxOpt} , should track the deviation: when the deviation is small, then only a small boost or cushion is needed and P_{TxOpt} can be lowered so that RSS stays close to RSS_{min}; when the deviation is large, then P_{TxOpt} should have a large boost or cushion so that even the steepest drops in RSS stay above RSS_{min}.

Mobility adds a new source of RSS variation. In Figure 1, movement between the transmitter and receiver increases/decreases the long-term RSS average. Our algorithm uses "significant" changes in the RSS average to detect mobility. Given an instantaneous estimate of the RSS for a received packet, the algorithm computes both an exponentially weighted moving average of the mean RSS value RSS_ave[n] as well as the variance in the RSS, RSS_dev[n].

$$RSS\_ave[n] = \alpha * RSS\_ave[n-1] + (1-\alpha) * RSS[n] \qquad (3)$$

$$RSS\_dev[n] = \beta * RSS\_dev[n-1] + (1-\beta) * |RSS[n] - RSS\_ave[n]| \qquad (4)$$

For example, in Figure 1, the smoothed RSS_ave mean was calculated using a value of α=0.7, thereby emphasizing the historical mean and deemphasizing the instantaneous or most recent RSS behavior.

Given estimates of the RSS mean and deviation from Equations 3 and 4, our algorithm records or "pegs" both of these values at the time when the last request to adjust the transmit power was sent from the receiver to the sender. The *j*'th adjustment to the optimum transmit power is also recorded, $P_{TxOpt}[j]$ As each new packet arrives, the smoothed RSS mean is calculated at the receiver according to Equation 3. If the smoothed RSS mean differs by more than a chosen fixed threshold from the "pegged" RSS mean at the last adjustment of the transmit power, then the algorithm deems that a "significant" long-term change in the RSS has taken place, probably induced by mobility but perhaps also by momentary shadowing. In such a case, the optimum transmit power at time *n* given *j-1* previous adjustments of the transmit power is recalculated as follows:

$$P_{TxOpt}[j] = P_{TxOpt}[j-1] - RSS\_ave[n] + RSS_{min} + RSS\_dev[n] \quad (5)$$

When mobility is detected, the smoothed deviation is added to RSS_{min} and the path loss term $P_{TxOpt}[j-1]$ - RSS_ave[n], thereby also adapting to multipath-induced variations and keeping below-threshold packet losses to a minimum. The threshold chosen to trigger the "significant" long-term change remains fixed at 2 dBm, which corresponds to the falloff in signal strength over about 10 m, which is a distance a walking individual could reasonably traverse at a rate of 1.5 m/s [Sheth].

A key remaining objective is to determine the values of α and β that result in the fewest below-threshold packet losses. However, the additional complication is that mobility also causes RSS fluctuations. Therefore, our additional objective is to limit the number of false positives where short-term multipath-induced fluctuations in RSS are mistaken for long-term fluctuations due to mobility.

III. PERFORMANCE ANALYSIS

The experimental setup that was used to implement transmit power control used a callback mechanism to extract the RSS for each packet. The transmit power was reset between two user-level peer processes on separate 802.11 laptops. Figure 2 shows the setup used to calculate the energy savings due to transmit power control of the wireless card operating in ad-hoc mode, similar to [Feeney]. By sampling the voltage drop across the wireless card using a DAC, we observe that a *maximum* energy savings of 25% can be achieved, including the idle energy consumption. Further details of the setup can be found in [Sheth].

To determine the optimal values of α and β, we needed to design an experiment that is repeatable and at the same time not confined to simulations. Thus the algorithm was analyzed by taking a set of RSS samples for a fixed transmit power for distances of 3m,5m,7m and 9m between a source and a destination node, i.e. separate 802.11 laptops.

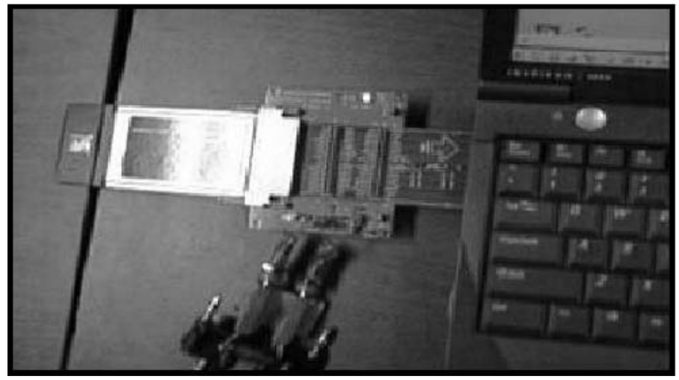

Figure 2: Basic setup used to measure the energy consumption of the card.

A. *Static Network Analysis*

For the optimal value of α, the number of false positives should be minimized, i.e. when there is no motion, ideally the number of times when mobility is detected should be zero despite the multipath fluctuations. We constructed a stationary scenario, collecting RSS measurements at set distances of 3m, 5m, 7m and 9m. For each distance, the adaptive algorithm was tested over a set of α values ranging from 0.1 to 0.9 in steps of 0.1. Figure 3 shows the number of false positives generated by the algorithm for an RSS trace where the source node is transmitting at 13 dBm. Figure 3 reveals a clear pattern across all distances in which the number of false triggers decreases with increasing α. Values of α from 0.7 to 0.9 resulted in the fewest false positives. High values of α (0.9) would reduce the responsiveness of our detection mechanism to true mobility, since the heavily smoothed RSS would respond sluggishly to rapid changes attributable to true mobility. Hence we determined an optimal value of α of 0.7. This analysis was performed for different transmit powers(20dBm/100mW, 17dBm/50mW and 13dBm/20mW) and the optimal values of α remained at 0.7.

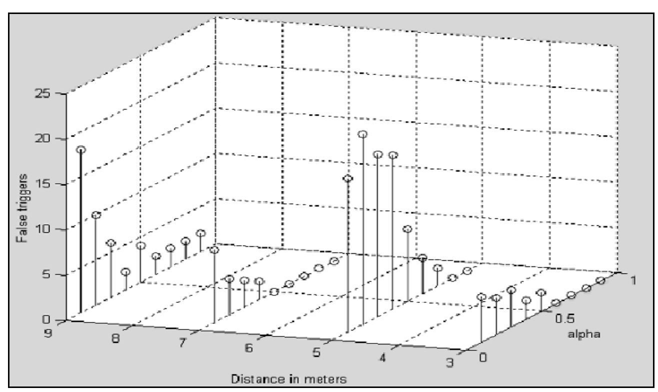

Figure 3: False triggers for alpha varying from 0.1 to 0.9 and source node transmitting at 13 dBm.

B. *Analysis in Presence of Mobility*

To analyze the behavior of the algorithm in presence of mobility in the network and arrive at the optimal value for the constant β, we collected RSS samples for a set of mobility traces with the transmit power of the source node set to a fixed power. As discussed in Section 2 Equation 5, the new transmit power also needs to be a function of the deviation in the RSS to reduce the number of below-threshold packet losses where RSS dips below RSS_{min} during periods of high up and down swings. For this analysis, we set the threshold to 0dBm (lowest transmit power that can be set on the card) and counted the number of times the RSS dips below this simulated threshold for different values of β. We observed that the negative false triggers were high for lower values of β (0.1-0.2) and the false triggers were nearly constant for values of β in the range of 0.3-0.6, tapering to the lowest values for β >= 0.7. Again, because the highest values of β do not provide a good local estimate of the most recent deviation, we choose the smallest β for which the number of below-threshold packet losses were minimum, namely the optimal β = 0.7.

Figure 4 demonstrates the actual motion detection points generated by the adaptive algorithm using a value of $\alpha = 0.7$. The trace is the exact same one as shown in Figure 1, e.g. static then mobile then static, but only the RSS_ave curve is plotted. The trigger points at which motion is detected are shown as black squares and correspond closely with intuition.

IV. CONCLUSION

This paper presents a distributed adaptive transmit power control algorithm for wireless networks that adapts to mobility despite the presence of multipath-induced noise. The algorithm calculates exponentially weighted moving averages of the received signal strength's mean and deviation. Significant changes in the long-term mean are used to detect motion and distinguish it from short-term multipath variations. At each motion event, the new optimum transmit power must account for the smoothed deviation to avoid excessive packet loss when highly variable RSS dives below the minimum reception threshold.

V. REFERENCES

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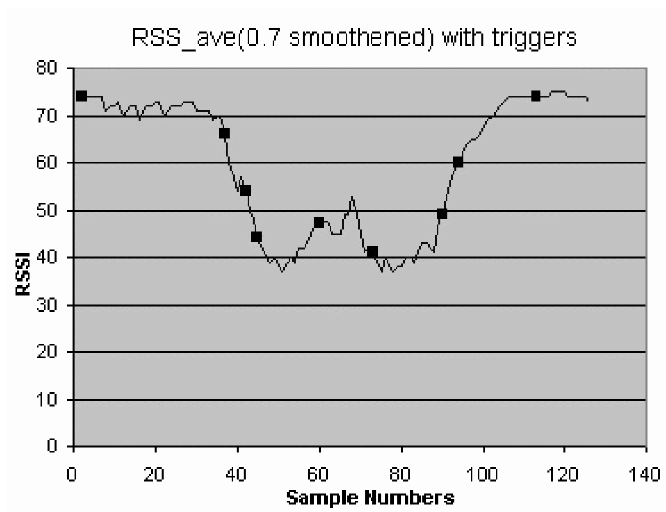

Figure 4: RSS_ave with trigger positions detecting true mobility.